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Alternatives to Raised Pavement Markers (RPMs)




Thomas M. Brennan

Stuart R. Mitkey

Darcy M. Bullock

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AUTHORS

Thomas M. Brennan, PhD, PE
Sr. Research Scientist
Lyles School of Civil Engineering
Purdue University

Stuart R. Mitkey
Graduate Research Assistant
Lyles School of Civil Engineering
Purdue University

Darcy M. Bullock, PhD, PE
Professor of Civil Engineering
Lyles School of Civil Engineering
Purdue University
(765) 494-2226
darcy@purdue.edu
Corresponding Author

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16. Abstract

Empirical evidence shows that raised pavement markers are an ongoing maintenance challenge. Furthermore, a dislodged RPM opens an ingress point for water to reach the sub pavement, potentially reducing the design life of the pavement. To address this issue, Indiana conducted an evaluation of centerline rumble stripes (CLRSs) as an alternative to RPMs on rural, non-interstate, roadways.

Five pilot test sites consisting of 41.2 miles of roadway were constructed to evaluate CLRS performance in multiple regions of Indiana under various pavement conditions. CLRS were subsequently incorporated into INDOT's 2013 Goals and approximately 238 project miles were programmed for construction. The project team participated in the development of a new specification for use in contract lettings after September 1, 2013.

This technical report summarizes that evaluation, briefly summarizes the project background and development of CLRS specifications, provides detailed photos of a Fall 2013 deployment, and summarizes the post—construction close out meeting held on December 4, 2013.

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EXECUTIVE SUMMARY

ALTERNATIVES TO RAISED PAVEMENT MARKERS (RPMs)

Introduction

Empirical evidence shows that raised pavement markers (RPMs) are an ongoing maintenance challenge. Furthermore, a dislodged RPM opens an ingress point for water to reach the sub pavement, potentially reducing the design life of the pavement. To address this issue, Indiana conducted an evaluation of painted centerline rumble stripes (CLRSs) as an alternative to RPMs on rural, non-interstate roadways.

Five pilot test sites consisting of 41.2 miles of roadway were constructed to evaluate CLRS performance in multiple regions of Indiana under various pavement conditions.

Findings

CLRS can reduce target crashes by 45% and ELRS can reduce target crashes by 35%, in large part by effectively alerting drivers and providing them an opportunity to correct their course before crossing the centerline or leaving the roadway. The corrugation can be particularly effective during periods of decreased visibility and/or adverse weather conditions (see Figures 1 and 2). If both CLRS and ELRS are being considered on sections with wide shoulders, consideration should be given to using edgeline corrugations in lieu of edgeline rumble stripes.

This technical report summarizes the project background and development of CLRS specifications, provides detailed photos of a fall 2013 deployment, and summarizes the post-construction close-out meeting held on December 4, 2013.

Implementation

CLRSs were subsequently incorporated into INDOT's 2013 goals and approximately 238 project miles were programmed for construction. Appendix A and Appendix B of the report contain the supporting documents developed in collaboration with INDOT for the September 2013 letting of projects with rumble stripes. Appendix C of the report contains photos of the project construction and a link to a video documenting the construction process.

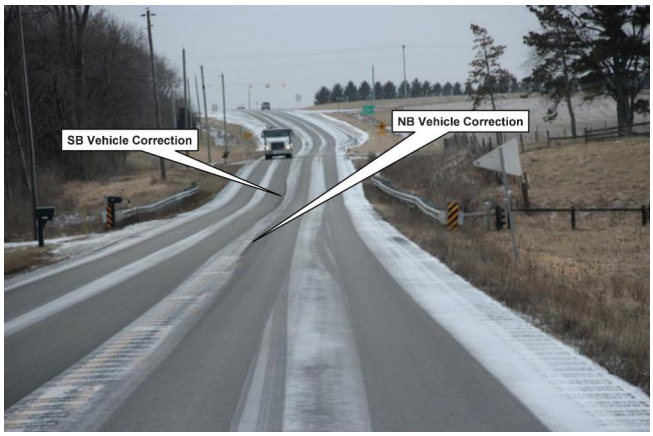

Figure 1 Example wheel tracks of vehicle that corrected after drifting onto the centerline rumble strip (US 231 north of Crawfordsville after a light snow, 2012).

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1. INTRODUCTION

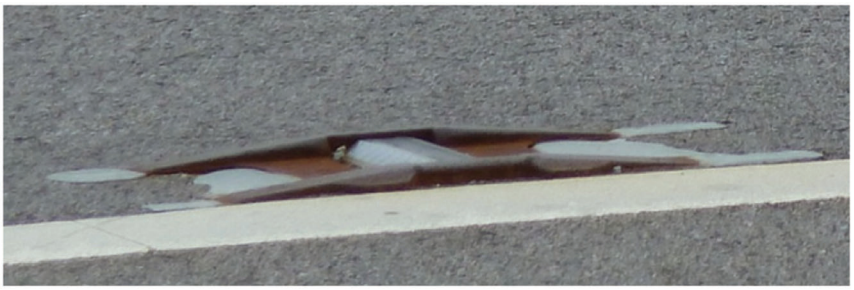
RPMs can become damaged (Figure 1.1b) or occasionally dislodged (Figure 1.2) from snowplow operations or heavy vehicle traffic. The intent of the study was to identify an alternative to Raised Pavement Markers (RPMs) (Figure 1.1a) and develop an implementation plan. Any proposed RPM alternative needs to provide similar or better safety performance on rural routes and be cost effective to construct.

As the study progressed, painted centerline corrugations, henceforth called centerline rumble stripes (CLRS) or generally referred to as rumble stripes (*1–3*), was identified to be a viable alternative to RPMs. The CLRS provided improved retroreflective values when compared to a standard painted line and met minimum FHWA retroreflective values for standard painted lines without RPM enhancement (*4*). It was further determined that the same application could be used to improve visibility on edgeline rumble stripes (ELRS). Examples of the improved visibility in nighttime dry and wet conditions for CLRS and ELRS are shown in Figure 1.3. It was observed that a rumble stripe not only improved visibility during wet conditions, but also increased the durability of pavement markings because some of glass beads were below the plane of a snow plow blade (Figure 1.4).

Finally, if both CLRS and ELRS are being considered on sections with wide shoulders, consideration should be given to using edgeline corrugations in lieu of edgeline rumble stripes.

Five pilot test sites consisting of 41.2 miles of roadway (Figure 1.5 and Table 1.1) were used to evaluate rumble stripe qualitative and quantitative performance, the associated construction costs, and construction constraints to define a new specification and detail drawing to be used by INDOT. This report is divided into four chapters:

- Chapter 1 provides an introduction to the project.
- Chapter 2 summarizes peer state implementation of CLRS and ELRS.
- Chapter 3 summarizes construction specifications and processes.
- Chapter 4 summarizes recommendations from the December 4, 2013, post-construction meeting.
- Appendix A contains a Design Memorandum (July 26, 2013)
- Appendix B contains construction specifications (September 1, 2013)
- Appendix C contains detailed photos of the construction of the SR 25 deployment of CLRS and ELRS in Shadeland, Indiana, that were constructed based upon documents in Appendix A and B during fall 2013. Appendix C also contains a link to a video that summarizes those construction activities.



(a) New RPMs

(b) Damaged RPM

Figure 1.1 RPMs installed fall 2010 along SR 25 near Shadeland, Indiana. Several were damaged prior to the plow season. November 2010.

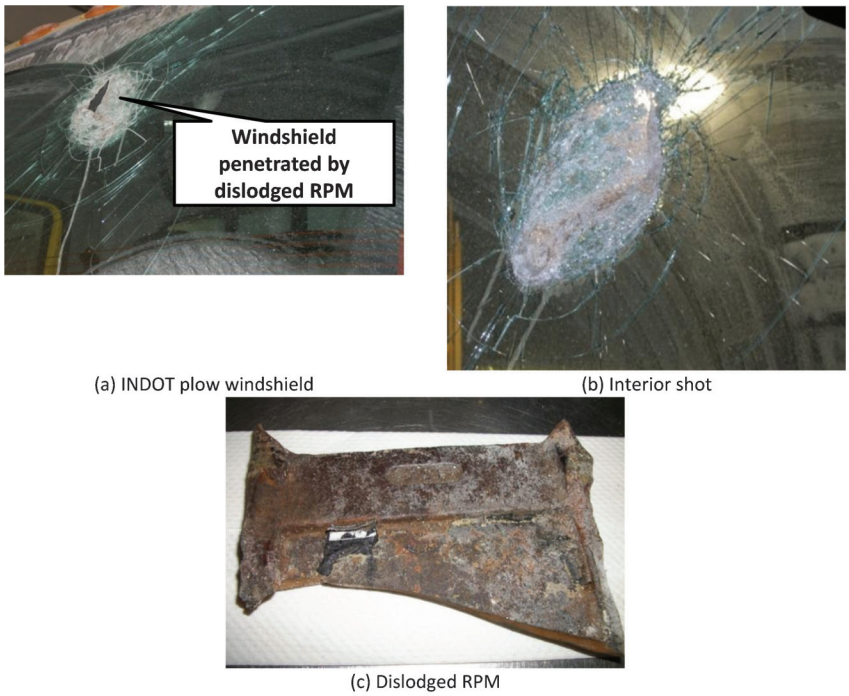


Figure 1.2 Snowplow windshield damage caused by a dislodged RPM. Photos courtesy Stacey Flick, INDOT LaPorte District.

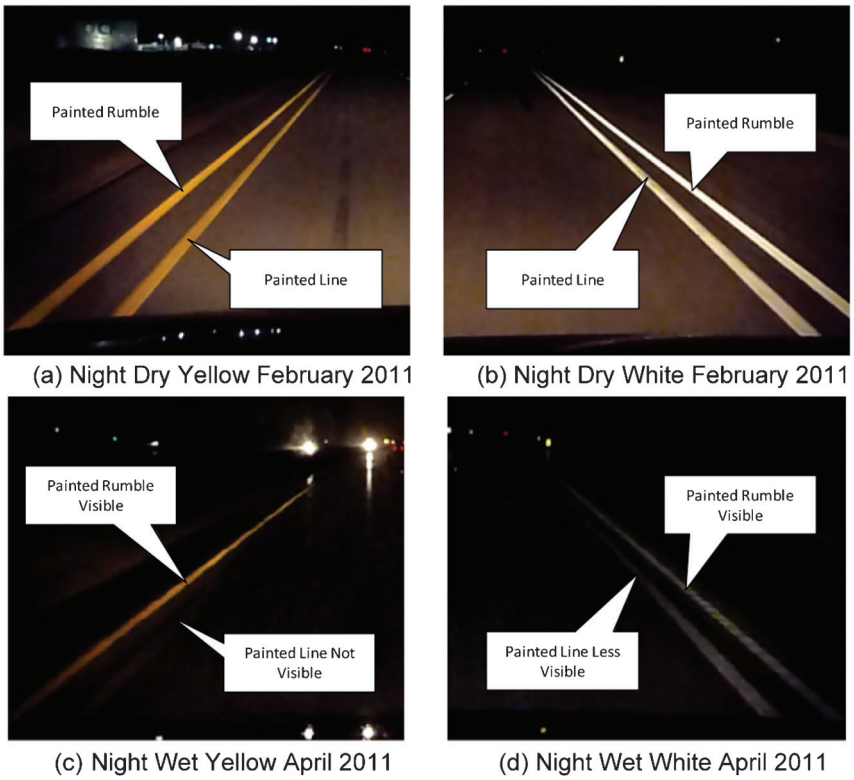
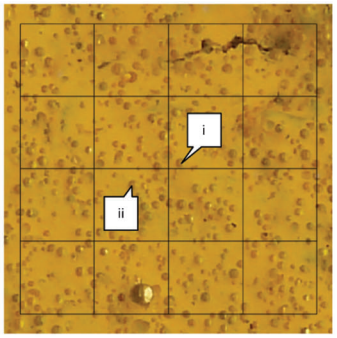
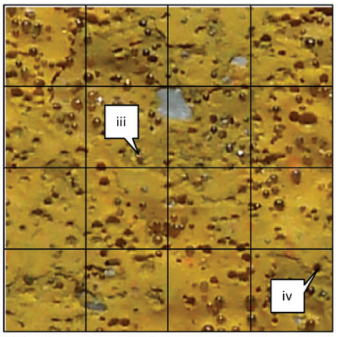


Figure 1.3 SR 28 Screen Images from driving videos in test zone with standard INDOT pavement marking with glass beads. Photos courtesy Alex Hainen and Steve Remias, Purdue University.



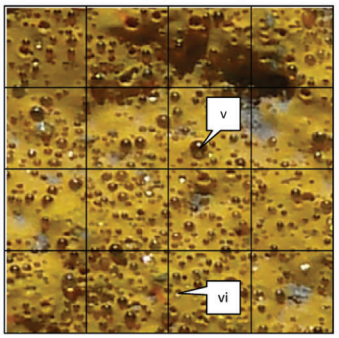
345 Beads

(a) Yellow line before winter; (i, ii) glass beads. (November 2010)



149 Beads

(b) Yellow line after winter; (iii) glass bead, (iv) missing glass bead. (March 2011)



244 Beads

(c) Yellow rumble bottom after winter; (v) glass bead, (vi) missing glass bead. (March 2011)

Figure 1.4 High resolution photography of a 1″ × 1″ sample of INDOT beads before and after winter snow plowing season.

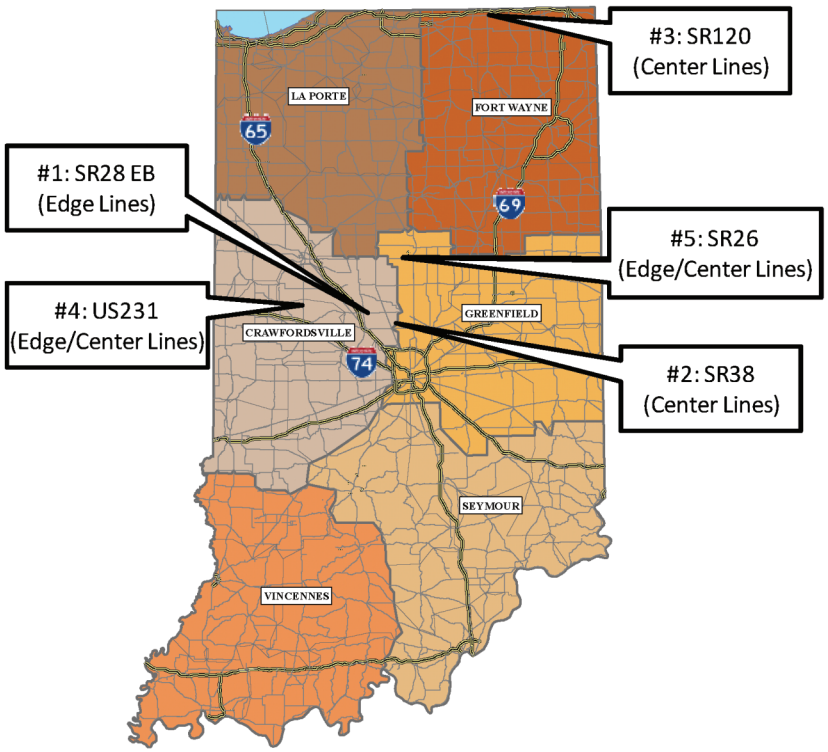


Figure 1.5 Indiana pilot studies for edge and centerline rumble stripes.

TABLE 1.1
Indiana pilot study project information

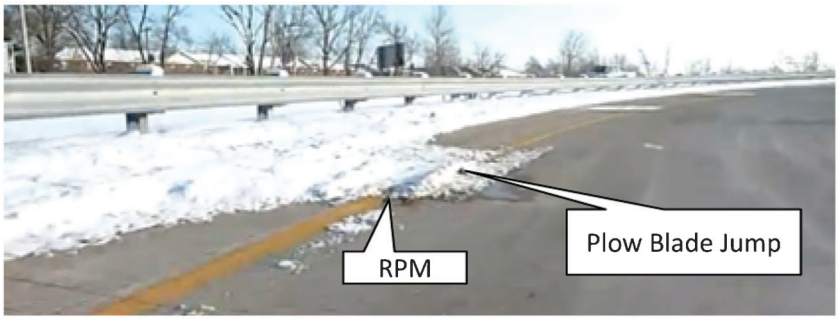
Road	Limits	Length (mi)	Year	County	Center/Edge	Roadway Width	Shoulder Width	Notes
SR 28	CR 700W to CR450W	4	2012	Newton	Y/Y	24′	6′	First test project established to test viability of CLRS/ELRS.
SR 38	SR 39 to US 421	8.1	2011	Clinton	Y/N	22′	0′ var. +	Added after letting. Length estimated.
SR 120	SR 13 to SR 5	5.3	2011	Elkhart/Lagrange	Y/N	22′	5′ to 7′	Added after letting. Length estimated.
US 231	I-74 to N of US 28	18.5	2012	Montgomery/Tippecanoe	Y/Y	24′	2′	Length derived by total milled corrugations/3.
SR 26	4.5 mi E of SR 29 to 2.2 mi W of US 31	5.3	2012	Howard	Y/Y	24′	8′	Added after letting. Length estimated. West of SR29 narrower.
Total miles		**41.2**						

2. BACKGROUND

Many crashes occur on rural roads as a result of lane departure related crashes (*2,5,6–8*). Many two-lane and four-lane rural roads lack medians and are not lighted. Although FHWA suggests retroreflectivity standards for painted pavement markings, studies show that additional measures can be taken to reduce lane departure crashes (*7,9*). RPMs are one common technology used in conjunction with painted lines. Concerns with using RPMs include expensive installation, high maintenance costs and susceptibility to dislodgement as the roadway degrades (*3,9–11*). RPMs also impact winter snowplow operations by causing the plow blade to jump, as shown in Figure 2.1a, and consequently missing the snow directly behind the RPM. While some snowplow operators cite the RPMs as helpful indicators of lane presence, this impact is likely damaging to the plow, RPM, and surrounding pavement.

Over the past two decades centerline rumble stripes (CLRS) have been installed as a safety enhancement in many states across the nation. However, when this study began, little research had been done to document the retroreflectivity of the paint within the rumble stripe. In seeking an alternative for RPMs, this study evaluated the retroreflectivity of rumble stripes compared to standard painted lines (Figure 2.2) (*12,13*). Peer states and national guidance report safety-benefit to cost ratios of 50:1 or better have been documented, with some ratios over 100:1 having been reported, Table 2.1 (*7,14,15*).

A comparison plot from PennDOT (*6*), Figure 2.3, shows an apparent correlation between miles of centerline rumble strip installed and reduction of head on fatalities. Similar data from Washington State are seen in Figure 2.4 (*16*). These reductions suggest, perhaps, that the audible warnings and imposed vibrations provided by CLRS are more effective in protecting inattentive drivers than increased visibility alone.



(a) Area of missed snow removal

(b) Replaced RPM

Figure 2.1 RPM impact on US 231 on ramp in West Lafayette, Indiana. January 2011. Photos courtesy Alex Hainen, Purdue University.

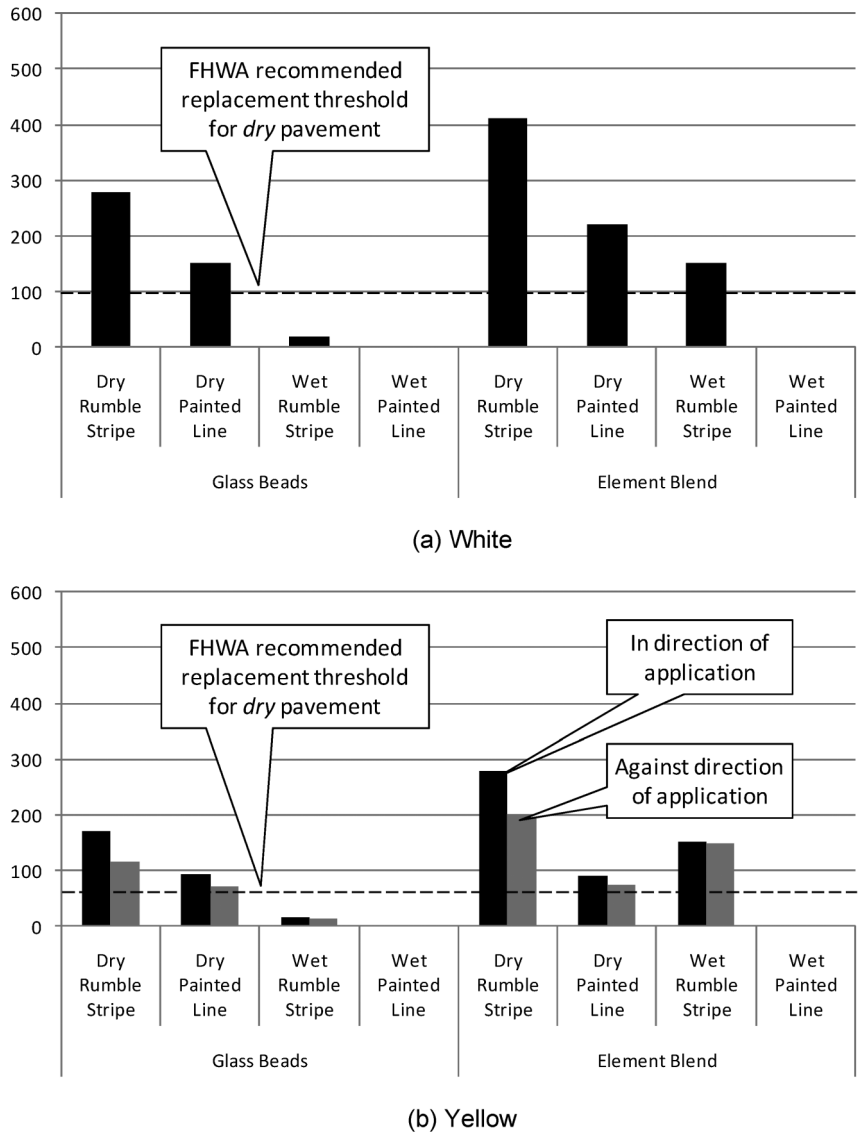


Figure 2.2 Comparison of mean retroreflectivity measurements for standard glass beads and proprietary 3M Element blend.

Federal Highway (FHWA) reports CLRS can reduce target crashes by 45% and ELRS can reduce target crashes by 35% (*2,5*), in large part by effectively alerting drivers and providing them an opportunity to correct their course before crossing the centerline or leaving the roadway (*18*). The corrugation can be particularly effective during periods of decreased visibility and/or adverse weather conditions (Figure 2.5, Figure 2.6).

TABLE 2.1
Reported centerline rumble stripe benefit/cost ratios

State	Benefit to Cost Ratio
Delaware	110:1
Maine	50:1
Nevada	30:1, 60:1
New York	75:1

CLRS are being deployed by multiple agencies as an alternative to RPMs. Additionally, the results of this study indicate that ELRS enhance nighttime line visibility, while providing an auditory and vibratory feedback of lane departure to inattentive drivers. A collateral benefit of ELRS and CLRS is the potential increase in the retroreflective durability of the lines, particularly in areas with substantial winter plowing operations. In November 2011 the FHWA published *Center Line Rumble Stripes Technical Advisory T 5040.40*, which briefly summarizes much of the centerline rumble stripe data collected in the past decade (*2*). Of key importance to Indiana's implementation of CLRS and ELSR is the FHWA statement:

> *"The practice (of striping centerline rumble strips) can also increase the longevity of the markings, particularly within the rumble, due to reduced wear from tires and added protection from plowing activity."*

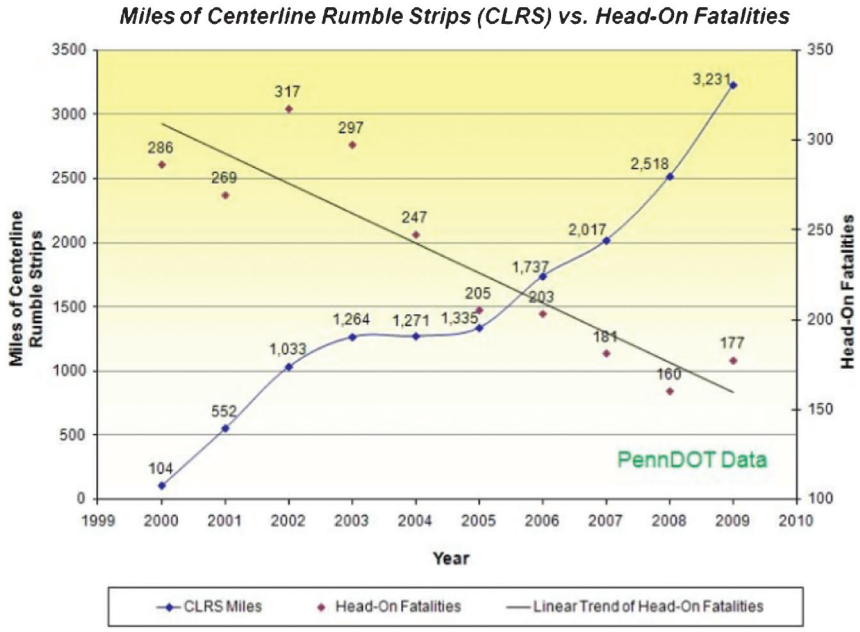


Figure 2.3 Reduction in head-on crashes in Pennsylvania.

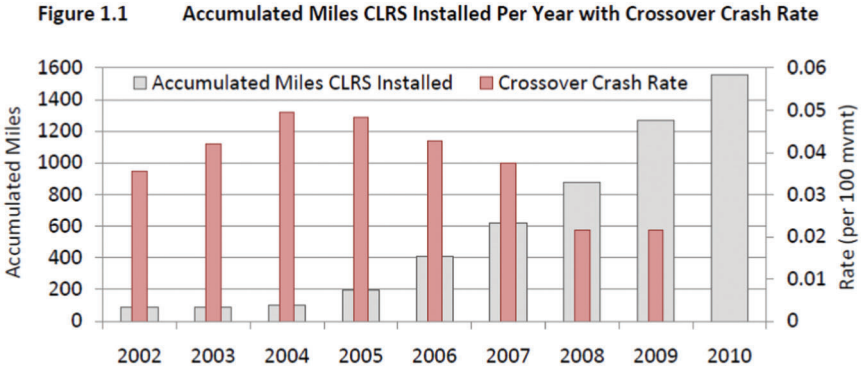


Figure 2.4 Reduction in crossover crash rate with respect to CLRS installation in Washington State.

A portion of the research conducted for this report evaluated qualitative and quantitative retroreflectivity to justify this statement. The retroreflectivity value for rumble stripes compared to standard lines is documented in the Journal of Transportation ITE (*12*) and Road and Bridge Magazine (*13*). In these publications, the retroreflectivity of CLRS and ELSR outperformed the standard pavement markings after one winter season (Figure 1.5). It was also documented that the standard line degraded faster than the rumble stripes, indicating an opportunity to potentially decrease the frequency of painting over the lifecycle of the pavement.

Figure 2.5 Examples of snow event that may cause lane departure (US 231 north of Crawfordsville in 2012).

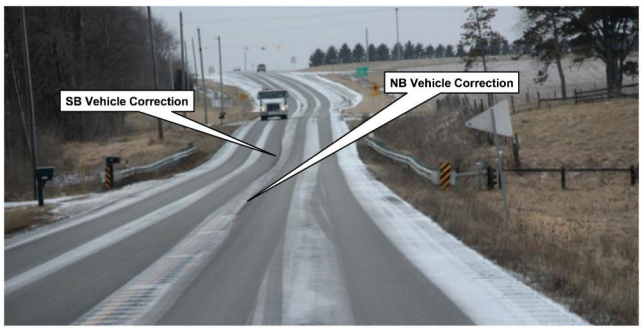


Figure 2.6 Example of vehicle correction after hitting the centerline rumble strip, located on US 231 north of Crawfordsville, Indiana, after a light snow, 2012.

3. CONSTRUCTION SPECIFICATION AND DETAILS

There have been a number of installations of CLRS and ELRS across the state (Figure 1.4). The projects listed in this figure had all been constructed on a change order to the original contract. The lessons learned during these early deployments were used to develop the rumble stripe design detail (Figure 3.1, Figure 3.2, and Figure 3.3), as well as the technical memorandum that establishes general application guidance (Appendix A) and the design specifications (Appendix B).

3.1 New Construction Installation

The series of images shown in Figure 3.4 (a–f) depict the sequence of events and respective equipment typically used to install centerline rumble strips on new pavement based on the drawing details for CLRS provided in Figure 3.1, Figure 3.2, and Figure 3.3. The process varies dependent on site conditions and the needs for the agency. The same process can be applied to ELRS. For retro-fit projects, the process would exclude Figure 3.4a, and would potentially include the removal of RPM lens (when present) depending on existing site conditions.

3.2 Installation Configurations

Examples of some of the marking configurations on a retro-fit installation along US 231 north of Crawfordsville, Indiana, are shown in Figure 3.5 and Figure 3.6.

3.3 Cost Estimates

Table 3.1 shows the installation cost of RPMs at 40′ and 80′ intervals with both thermoplastic and paint pavement markings to accommodate typical design specification encountered by INDOT (although thermo plastic installation has only been performed on one test site as of the report writing). The installed RPM cost obtained from INDOT contracts is $14.15, which is close to the approximate cost of the material. However, installation costs of up to $60 per RPM (*10*) where found during the literature review. Table 3.2 shows the installation costs of CLRS based on INDOT contract prices. Comparing Table 3.1 to the CLRS costs in Table 3.2, the RPM installation cost is more expensive (Table 3.1a) at 40′ then the CLRS and less expensive (Table 3.1b) at 80′. However, because the RPM costs are conservative, it is expected that in both cases RPM installation would be more expensive.

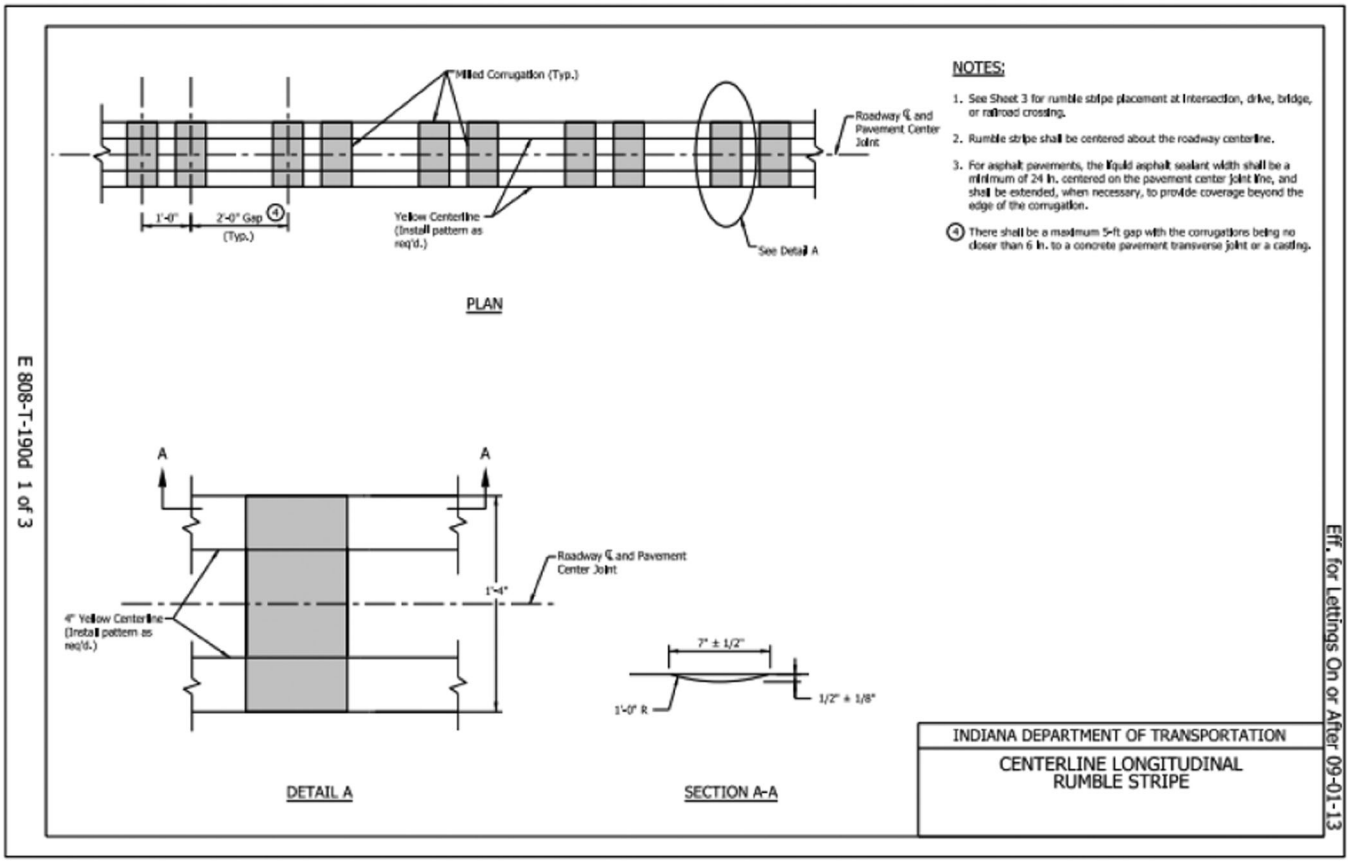


Figure 3.1 Rumble stripe detail page 1 of 3.

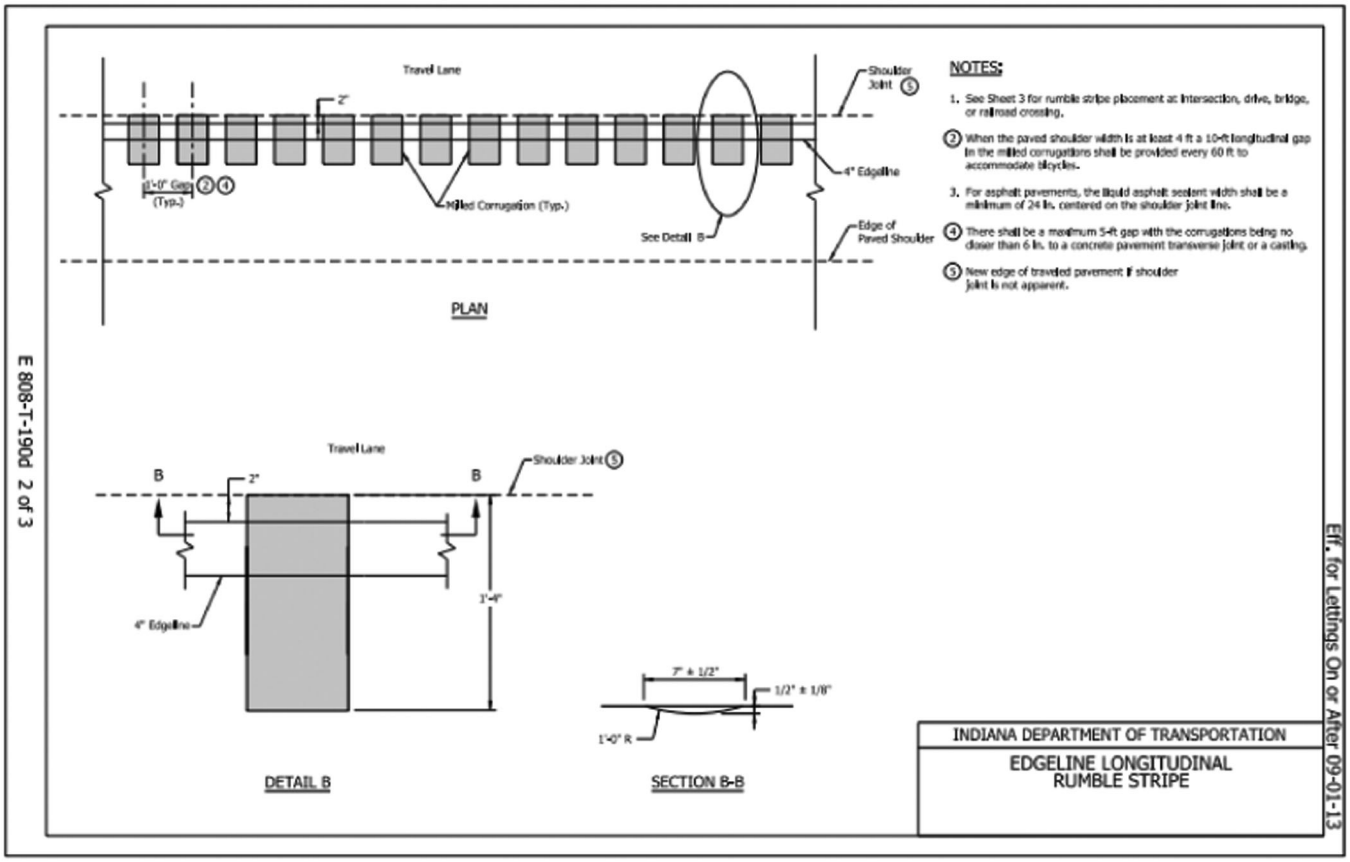


Figure 3.2 Rumble stripe detail page 2 of 3.

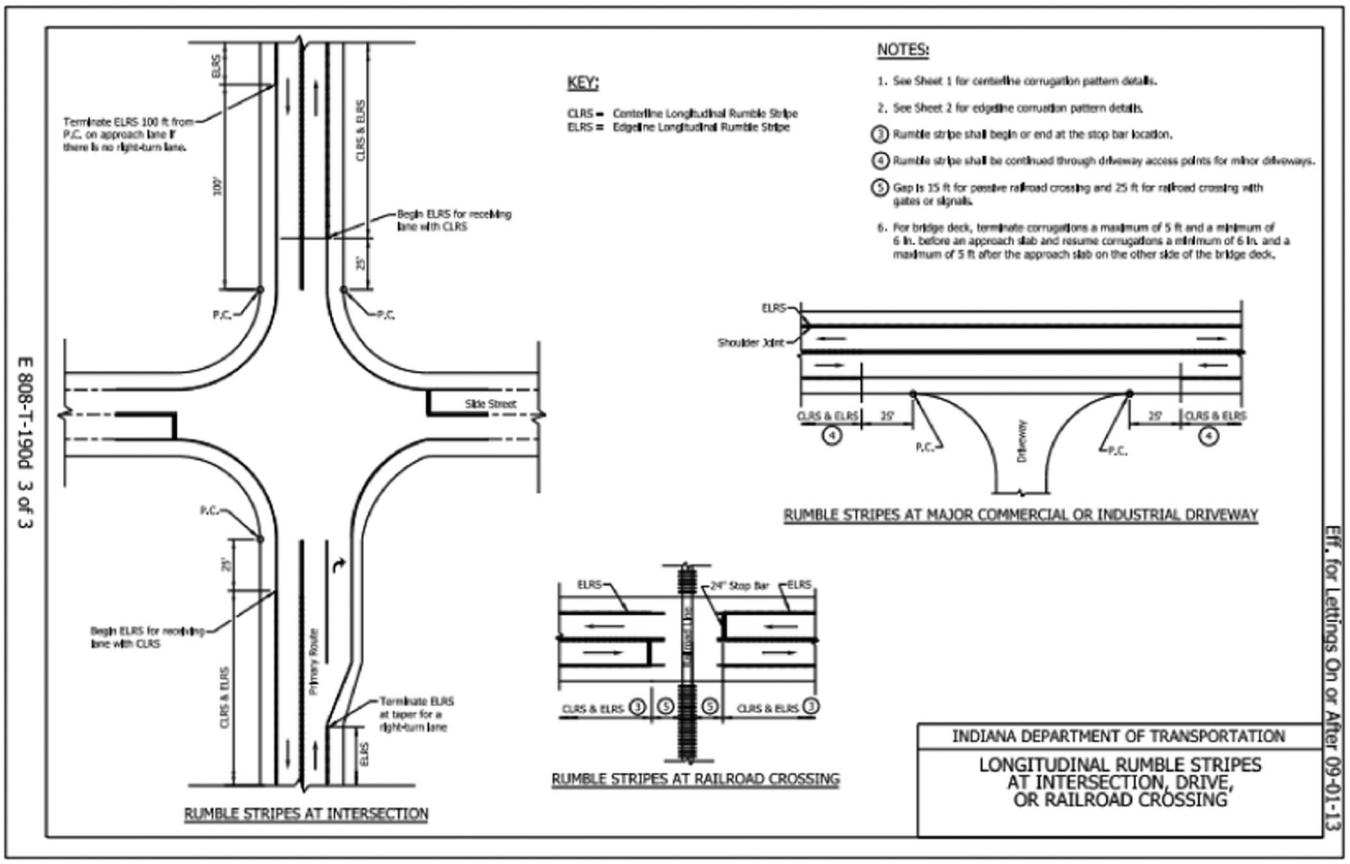
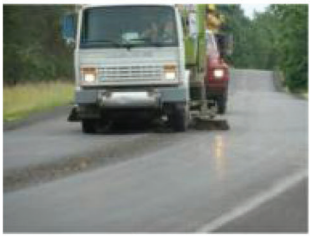


Figure 3.3 Rumble stripe detail page 3 of 3.

(a) Vertical joint sealant (new construction only)

(b) Corrugation grinding head, 16”

(c) Milling machine



(d) Sweep and vacuum

(e) Newly Cut Rumble (16 in wide)

(f) Fog sealant

(g) Painting truck

(h) Finished painted centerline rumble stripe

Figure 3.4 Centerline rumble stripe installation sequence on new pavement.

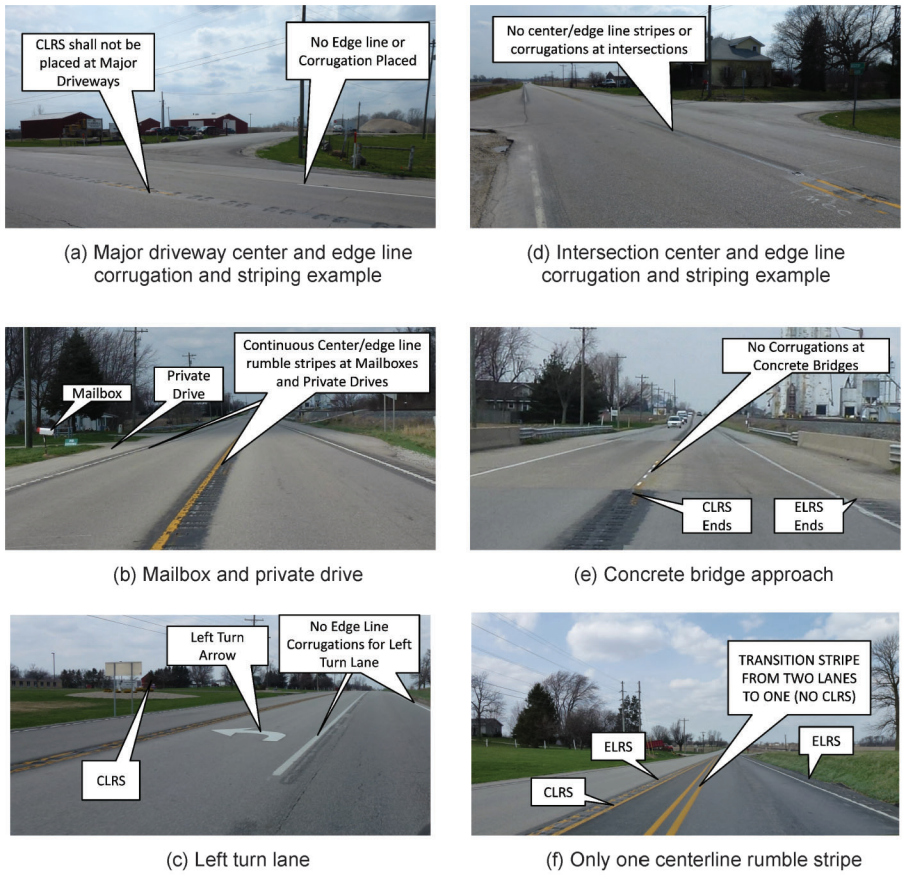


Figure 3.5 Examples of corrugations and striping installations at specific locations along US 231.

The use of CLRS is expected to reduce life cycle costs by as much as 63% and 52% when comparing the biennial re-painting CLRS costs (Table 3.5b) to RPMs at 40 ft (Table 3.4a) and 80 ft intervals (Table 3.4b), respectively.

Figure 3.6 Roadway center and edgeline corrugation and striping example at railroad crossing along US 231.

TABLE 3.1
RPM installation costs using INDOT contract data

RPM 40′ Install—Using INDOT Contract Prices			
	Quantity per Mile	**Unit Cost**	**Cost per Mile**
(a) RPM installation costs when installed at 40′ intervals			
RPM (install)	132	$14.15	$1867.80
Thermo (if)	5280	$.36	$1900.80
Paint (if)	5280	$.13	$686.40
Total with Thermo			**$3768.60**
Total with Paint			**$2554.20**
RPM 80′ Install—Using INDOT Contract Prices			
	Quantity per Mile	**Unit Cost**	**Cost per Mile**
(b) RPM installation costs when installed at 80′ intervals			
RPM (install)	66	$14.15	$933.90
Thermo (if)	5280	$.36	$1900.80
Paint (if)	5280	$.13	$686.40
Total with Thermo			**$2834.70**
Total with Paint			**$1620.30**

TABLE 3.2
CLRS price breakdown

CLRS Install—Using INDOT Contract Prices			
	Quantity per Mile	Unit Cost	Cost per Mile
RPM (install)	5280	$.20	$1056.00
Thermo (if)	5280	$.36	$1900.80
Paint (if)	5280	$.13	$686.40
Total with Thermo			**$2956.80**
Total with Paint			**$1742.40**

TABLE 3.3
Lifecycle cost of centerline rumble stripe with paint applied at the installation

CLRS Lifecycle Cost Per Centerline Mile—Using INDOT Prices		
	Install Cost	15 Year Estimate
(a) Annual re-painting		
Milling (install)	$1056.00	$1056.00
Painting (install)	$686.40	$686.40
Re-painting (14 years)	n/a	$2956.80
Total		**$4699.20**

CLRS Lifecycle Cost Per Centerline Mile—Using INDOT Prices		
	Unit Cost	Cost per Mile
(b) Biennial re-painting		
Milling (install)	$1056.00	$1056.00
Painting (install)	$684.40	$686.40
Re-painting (14 years)	n/a	$1478.40
Total		**$3220.80**

4. CONCLUSIONS

CLRS and ELRS provide a well-documented safety benefit (*2,5*) and the corrugation protects a substantial portion of the glass beads from snow plow damage (Figure 1.5). Appendix A and Appendix B contain the documents that were developed for the September 2013 letting for deploying approximately 48 project miles in 2013. Appendix C contains a series of photos from one of those projects on SR 25 adjacent to Shadeland and West Point.

During the December 4, 2013, post-construction meeting with the contractor, the following recommendations were identified.

1. Contract documents should include an item for placing a drip line (Figure 4.1) along the center joint and/or between the centerline to provide horizontal control for placing the centerline rumble after the centerline markings are ground off.
2. Contract documents should include an item for placing a drip line to provide horizontal control for placing edgeline rumble.
3. Providing proper fog seal coverage was a challenge (Figure C.28 to Figure C.32). Further dialog is needed to identify recommended material and application procedure so that sufficient coverage (Figure C.34 to Figure C.36) is achieved in first pass, but without over application that increase curing time before lines can be painted.
4. Example construction photos and video contained in Appendix C should be provided to INDOT inspectors new to CLRS and ELRS in advance of a job to provide familiarity with the process.

Figure 4.1 Dripline placed between centerlines before centerlines are ground off.

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INDIANA DEPARTMENT OF TRANSPORTATION

Driving Indiana's Economic Growth

Design Memorandum No. 13-13
Technical Advisory

July 26, 2013

TO: **All Design, Operations, and District Personnel, and Consultants**

FROM: */s/ David Boruff*
David Boruff
Manager, Office of Traffic Administration
Traffic Engineering Division

SUBJECT: **Centerline and Edge Line Rumble Stripes**

REVISE: ***Indiana Design Manual*** **Sections 45-1.02(06), 76-3.02(05), & 76-3.02(06)**

EFFECTIVE: **Lettings on or after September 1, 2013**

INDOT has used raised pavement markers (RPMs), shoulder corrugations, and other supplementary measures to guide drivers along the correct travel path. Longitudinal rumble stripes are another method proving effective to this end. Longitudinal rumble stripes are the combination of milled corrugations with a longitudinal pavement marking installed within. They can be placed as centerline or edge line configurations. Rumble stripes reduce crashes caused by distracted, drowsy, or otherwise inattentive drivers who unintentionally drift from their lane. Research conducted by the Indiana Joint Transportation Research Program (JTRP) on the use of rumble stripes in lieu of RPMs showed that rumble stripes provide better delineation at nighttime and during inclement weather and reduce the Department's maintenance efforts.

The decision to specify rumble stripes should be made as part of the overall project scope of work. The District Technical Services Division should be consulted in determining whether a project should or should not include rumble stripes but in general rumble stripes should be implemented as follows:

General Conditions for the Use of Rumble Stripes. The combination of centerline and edge line rumble stripes generally should be specified for rural two-lane roadways where the posted or

statutory speed limit is greater than 50 mph. The use of only centerline or only edge line rumble stripes is discussed by roadway type in *Indiana Design Manual (IDM)* 76-3.02(06) item 1.

General Conditions that Preclude the Use of Rumble Stripes. Rumble stripes generally should not be specified for the following:

1. Urban segment. Urban for this definition is a function of roadway character and prevailing land use, not explicitly an urban functional classification.
2. Low-speed roadway. Low speed is considered less than 50 mph.
3. Location where certain pavement surface treatments are selected or a pavement warranty is active. The pavement surface type and age affect the decision to include rumble stripes.

Use of Rumble Stripes and RPMs. The use of RPMs in conjunction with rumble stripes for project specific circumstances requires the approval of the District Traffic Engineer.

Indiana Design Manual and *Standard Specifications*. *IDM* Sections 73-3.02(05) and (06) have been revised to provide specific guidance on the use of rumble stripes. These Sections are attached to this memo and should be reviewed for specific exceptions to the guidance herein.

Recurring Special Provision 808-T-190 and Recurring Plan Detail 808-T-190d provide additional requirements, pay items, and details for longitudinal rumble stripes and their proper installation, and can be found on the Department's website at http://www.in.gov/dot/div/contracts/standards/rsp/index.html.

Use of Shoulder Corrugations. *IDM* Section 45-1.02(06) has been revised to provide additional guidance for the use of shoulder corrugations due to the addition of edge line rumble stripes as an alternative treatment.

[P:\Structural Services\Design Memos\Signed\2013\13-13ta Rumble Stripes.doc]

45-1.02(06) Shoulder Corrugations

Shoulder corrugations should be considered for ~~a roadway designed as~~ a rural *multi-lane* facility. *The designer should contact the District Technical Services Division to determine whether shoulder corrugations should be provided in lieu of edge line rumble stripes. See Section 76-3.02(06) for additional information on longitudinal rumble stripes.*

The minimum paved width for an outside shoulder to provide shoulder corrugations is 6 ft. When guardrail, concrete barrier railing, or another type of roadside barrier is adjacent to an outside shoulder, such minimum paved width is 7 ft. The minimum paved width to provide median shoulder corrugations is 4 ft.

Shoulder corrugations should be milled, without regard to the shoulder-pavement material.

76-3.02(05) Raised Pavement Markers (RPMs)

Snowplowable RPMs provide a supplemental method of delineation and are a positive position guidance device. They should not be used as a replacement for standard pavement markings or conventional roadside delineation. The INDOT *Standard Drawings* provide details on the placement and color locations for RPMs. In addition, the following placement considerations should be reviewed.

1. Location. Site selection should be based primarily on the need for additional alignment delineation specifically in an area of frequently inclement weather (e.g., fog, smoke, rain) and in an area of low roadway illumination. RPMs placement should be considered where vehicles are leaving the roadway, an area showing excessive wear of existing pavement markings, an area with excessive skid marks, interchange ramp, etc. *RPMs that supplement the centerline or edge line pavement markings may be considered for urban highways, rural multilane highways, and rural two lane highways when the factors described in items 4 and 5 below are present and they do not meet the criteria for rumble stripes in Section 76-3.02(06). Under special circumstances, RPMs that supplement the centerline or edge line rumble stripes may be used with approval from the District Traffic Engineer.*

   RPMs that supplement lane lines should be considered for multi-lane highways when the factors described in items 4 and 5 below are present.

2. Pavement Life. RPMs should not be placed at a location that is scheduled for resurfacing or reconstruction within the next four years.

3. Illumination. RPMs may not be required at a location that is illuminated.

4. Traffic Volume. RPMs should be considered where AADT exceeds 2500 for a 2-lane roadway, or 6000 for a 4-lane roadway. On a lower-volume road, an engineering investigation should be conducted to determine whether RPMs are appropriate to supplement the standard traffic-control devices.

5. Spacing. The spacing for RPMs on a tangent section is 80 ft. Spacing for centerline RPMs used in conjunction with a no-passing zone may be reduced to 40 ft. Six RPMs at 40-ft spacing (240 ft) may be used in advance of and following a delineated no-passing zone. Consideration should be given to connecting two locations or zones of RPMs where the distance between them is less than 3000 ft. See the INDOT *Standard Drawings* for additional details for spacing at other locations.

6. Special Locations. RPMs should not be used exclusively with edge lines or gore markings. RPMs may be used at a pavement transition, one-way or narrow bridge, special channelization area, or where there is strong justification for installation of the devices.

7. Blue Retroreflectors. An RPM with blue retroreflectors should be specified where a fire hydrant is located within the roadway's right of way. Such an RPM should be specified only for a roadway where RPMs with yellow or white retroreflectors are to be installed.

   The RPM should be placed at an approximately right angle to the fire-hydrant location. It should be a two-way marker visible in both directions of travel. It should be placed in addition to RPMs with yellow or white retroreflectors.

   For a 3-lane roadway with a bidirectional left-turn lane, the RPM should be placed within the transverse limits of the yellow markings on the hydrant side of the bidirectional left turn lane.

   For a roadway of 4 lanes or more, the RPM should be placed within the transverse limits of the lane-line marking nearest the fire hydrant, but should not be placed within the transverse limits of the pavement-edge line.

   The locations of RPMs with blue retroreflectors should be shown on the plans. Quantities for such RPMs should therefore be incorporated into the quantities for other RPMs.

For a two-lane, two-way roadway, the RPM should be placed within the transverse limits of the center-line marking.

Local-public-agency (LPA) standards, if such exist, should be applied to a road under LPA jurisdiction. The District Traffic Engineer should be contacted to determine when an LPA's standards, if such exist, should apply on a Department-maintained route within the LPA's jurisdiction.

76-3.02(06) Longitudinal Rumble Stripes

A rumble stripe is the combination of milled corrugations with the longitudinal pavement marking line installed within. This combination provides improved retroreflectivity of the pavement marking and an audible and vibratory warning to a motorist leaving the travel lane. Rumble stripes are a supplemental means of reducing lane departures and may be specified with a new pavement surface project or in a stand-alone rumble stripe retrofit project. The decision to specify rumble stripes as part of a project should be confirmed by the District Technical Services Division.

When determining whether to specify rumble stripes the designer should consider the roadway type first. When rumble stripes should be specified based on roadway type, the presence of design elements that may preclude the use of rumble stripes should be checked. For the purposes of determining the need for rumble stripes the designation of rural or urban is a function of roadway characteristics and prevailing land use, not necessarily a location outside or inside an urban area boundary.

1. *Selection by roadway type.*

   a. *Rural two-lane and multi-lane undivided roads.*

      (1) *Segment with posted speed limits ≥ 50 mph. Centerline and edge line rumble stripes should be specified.*

      (2) *Segment with posted speed limits <50 mph. Centerline or edge line rumble stripes generally should not be specified, although special circumstances may justify their use, e.g. the presence of significant history of run-off-road, opposite direction side swipe, and head-on crashes.*

   b. *Rural multi-lane divided non-freeways.*

      (1) *Segment with posted speed ≥ 50 mph. Centerline rumble stripes are not applicable. Edge line rumble stripes may be specified on the inside or outside shoulders, or on both sides. Among other factors in this design decision is past traffic safety performance.*

      (2) *Segment with posted speed < 50 mph. Centerline rumble stripes are not applicable. Edge line rumble stripes generally should not be used, although special circumstances may justify its use.*

   c. *Rural freeway (interstate or non-interstate). Edge line rumble stripes generally should not be specified. Centerline rumble stripes are not applicable.*

2. *Design elements that preclude rumble stripes. Should the combination of centerline and edge line rumbles stripes not be viable the designer should specify the use of only centerline rumble stripes. When centerline rumble stripes alone are not viable then edge line rumble stripes alone should be specified.*

   a. *Centerline and edge line rumble stripes in combination. Centerline and edge line rumble stripes should not be used in combination when one or more of the following design elements are present:*

      (1) *the posted speed limit is less than 50 mph;*

(2) the design lane width is less than 11 ft;

(3) the design paved shoulder width is less than 2 ft;

(4) urban segment or a segment with a two-way left turn lane;

(5) chip seal (seal coat) surface within 1 year of surface application;

(6) pavement surface treatment with an active warranty, e.g. Microsurface or ultrathin bonded wearing course (UBWC) within 3 years of construction;

(7) rural segment with significant bicycle traffic and paved shoulder width is less than 4 ft; or

(8) rural segment where horse drawn vehicles are known to regularly use the shoulder and shoulder width is less than 10 ft.

Centerline rumble stripes only. Centerline rumble stripes alone are not normally used when one or more of the following design elements are present:

(1) the posted speed limit is less than 50 mph;

(2) the design lane width is less than 10 ft;

(3) urban segment or a segment with a two-way left turn lane;

(4) chip seal (seal coat) surface within 1 year of surface application; or

(5) pavement surface treatment with an active warranty e.g. Microsurface or UBWC within 3 years of construction.

Edge line rumble stripes only. Edge line rumble stripes alone are not normally used when one or more of the following design elements are present:

(1) the posted speed limit is less than 50 mph;

(2) the design paved shoulder width is less than 2 ft;

(3) urban segment;

(4) chip seal (seal coat) surface within 1 year of surface application;

(5) pavement surface treatments with an active warranty e.g. Microsurface UBWC within 3 years of construction;

(6) rural segment with significant bicycle traffic and paved shoulder width is less than 4 ft; or

(7) rural segment where horse drawn vehicles are known to regularly use the shoulder and shoulder width is less than 10 ft.

d. Retrofitted Rumble Stripes. Rumble Stripes should not be retrofitted on an existing pavement when an applicable design element noted above exists or when one or more of the following design elements are present:

(1). the existing pavement condition is poor as determined by the Division of Pavement Design or the District Pavement Engineer;

(2). along any segment that will be resurfaced within the next 3 years; or

(3). the section is under a pavement warranty that has not expired. Contact the District Pavement Engineer or see the INDOT intranet site for information on warranty sections:
http://intranet.indot.state.in.us/pdf/PavementPreservationWarrantyDates.pdf
Consultants may contact their project manager to obtain this information.

Rumble stripes generally should not be used in combination with centerline and edge line RPMs, but rather used instead of. In special circumstances RPMs may be specified with rumble stripes with approval from the District Traffic Engineer.

Unless directed by the District Traffic Engineer, thermoplastic should not be specified with longitudinal rumple stripes

INDOT Standard Specifications and Drawings provide details on the installation of rumble stripes. As shown on the Standard Drawings, the centerline and the edge line markings will be installed within the corrugation. Centerline corrugations should be gapped where turn lanes are developed at intersections or where two-way-left turn lanes are present. For centerline rumble stripes, the milled corrugations should follow the centerlines around channelizing islands or medians

The plans should show the rumble stripes with the pavement marking details. When edge line rumble stripes are included but no shoulder joint is present the typical cross sections of the plans should also show the location the new edge of traveled pavement. Separate payment should be made for the pavement markings, the milled corrugations, and in the case of a retrofit project, for the removal of existing lines.

~~76-3.02(06)~~ *76-3.02(07)* Surface Conditions [Rev. Sept. 2011]

09-01-13

808-T-190 LONGITUDINAL RUMBLE STRIPES

(Adopted 05-16-13)

The Standard Specifications are revised as follows:

SECTION 401, BEGIN LINE 458, DELETE AND INSERT AS FOLLOWS:

401.17 ~~Shoulder~~*Pavement* Corrugations

~~Shoulder~~*Pavement* corrugations shall be in accordance with 606.

SECTION 402, BEGIN LINE 81, DELETE AND INSERT AS FOLLOWS:

402.07 Mix Criteria

(a) Composition Limits for HMA *Transverse* Rumble Strip Mixtures

Transverse ~~R~~rumble strip mixtures shall be type A surface in accordance with 402.04. A MAF in accordance with 402.05 will not apply. Aggregate requirements of 904.03(d) do not apply.

SECTION 402, BEGIN LINE 278, DELETE AND INSERT AS FOLLOWS:

Transverse ~~R~~rumble strips shall be placed to ensure uniformity of depth, width, texture, and the required spacing between strips. A tack coat in accordance with 406 shall be applied on the pavement surface prior to placing the mixture. The tack coat may be applied with a paint brush or other approved methods.

SECTION 402, BEGIN LINE 346, DELETE AND INSERT AS FOLLOWS:

Transverse ~~R~~rumble strips shall be compacted with vibratory compacting equipment in accordance with 409.03(d)7 unless otherwise stated.

SECTION 402, BEGIN LINE 395, DELETE AND INSERT AS FOLLOWS:

402.17 ~~Shoulder~~*Pavement* Corrugations

~~Shoulder~~*Pavement* corrugations shall be in accordance with 606.

SECTION 402, BEGIN LINE 425, INSERT AS FOLLOWS:

HMA *Transverse* Rumble Strips ..... LFT

SECTION 501, BEGIN LINE 372, DELETE AND INSERT AS FOLLOWS:

501.24 ~~Shoulder~~*Pavement* Corrugations

~~Shoulder~~*Pavement* corrugations shall be in accordance with 606.

SECTION 502, BEGIN LINE 359, DELETE AND INSERT AS FOLLOWS:

502.19 ~~Shoulder~~*Pavement* Corrugations

~~Shoulder~~*Pavement* corrugations shall be in accordance with 606.

SECTION 606, BEGIN LINE 1, DELETE AND INSERT AS FOLLOWS:

SECTION 606 – ~~SHOULDER~~*PAVEMENT* CORRUGATIONS

606.01 Description

(a) All Corrugations

This work shall consist of placing corrugations in the ~~paved shoulders~~*pavement* in accordance with 105.03. Corrugations shall not be constructed within the limits of reinforced concrete bridge approaches or in bridge decks.

The operation shall be coordinated such that milled materials do not encroach on the pavement lanes carrying traffic and all milled materials are disposed of in accordance with 104.07. *When corrugations are installed for center line and edge line rumble stripes, milled materials shall be swept and vacuumed following the milling operation.*

The corrugation shall be constructed by cutting smooth strips in existing or newly constructed ~~shoulders~~ *pavement*. The operation shall be conducted by means of a cutting machine that provides a series of smooth cuts without tearing or snagging. The equipment shall include guides to maintain uniformity and consistency in the alignment of the strips.

Longitudinal rumble stripes are the combination of either the center line pavement marking placed in the center line corrugation or the edge line pavement marking placed in the edge line corrugation. They shall be installed as shown in the plans and as specified herein.

(b) Center Line and Edge Line Corrugations

When corrugations are installed for center line and edge line rumble stripes control points that are required as a guide for milling corrugations shall be spotted with paint for the full length of the road to be milled. Control points along tangent sections shall be spaced at a maximum interval of 100 ft. Control points along curve sections shall be spaced to ensure the accurate location of the milled corrugations. The location of control points shall be approved prior to the milling operations.

If snowplowable raised pavement markers exist where center line corrugations are being placed into the existing surface, the prismatic reflectors in these markers shall be removed and corrugations gapped a maximum of 60 in. and not within 6 in. of the markers.

In the presence of D-1 pavement joints or castings which conflict with the location of the corrugations, the corrugations shall be gapped a maximum of 5 ft and not within 6 in. of the joint or casting.

Corrugations installed within the HMA traveled way and on HMA shoulder contiguous with a HMA traveled way or a HMA auxiliary lane shall be sealed using liquid asphalt sealant in accordance with 401.15.

1. Installation Tolerances

Lateral deviation of milled center line or edge line corrugations shall not exceed 1 in. in 100 ft. The alignment of all pavement markings placed within rumble stripes shall be ± 1/2 in. of its specified location.

2. Maintenance of Traffic

The rumble stripe traffic control procedures shall be submitted to the Engineer and shall be in accordance with 808.08. Vehicles used in performing the milling, sweeper, vacuum or sealing operations shall have a rear escort vehicle that follows at a distance of 100 to 500 ft.

606.02 Method of Measurement

HMA and PCCP ~~shoulder~~*pavement* corrugations will be measured by the linear foot, measured parallel to the center line of the roadway. Gaps in PCCP ~~shoulder~~*pavement* corrugations at the D-1 joints will be included in the milled PCCP corrugations. *Gaps in pavement corrugations for castings will be included in the milled corrugations.*

606.03 Basis of Payment

HMA and PCCP ~~shoulder~~*pavement* corrugations will be paid for at the contract unit price per linear foot, when specified.

Payment will be made under:

Pay Item	Pay Unit Symbol
Milled HMA ~~Shoulder~~ Corrugations	LFT
Milled PCCP ~~Shoulder~~ Corrugations	LFT

The cost of removal of existing prismatic reflectors in rumble strip retrofit sections shall be included in the cost of the pay items.

Milling, sweeping, vacuum cleaning, operation protection and maintenance of traffic associated with these pay items and all necessary incidentals shall be included in the cost of the pay items.

Where corrugations are placed in an existing HMA surface, liquid asphalt sealant shall be included in the cost of the pay items.

SECTION 808, BEGIN LINE 53, INSERT AS FOLLOWS:

808.04 Longitudinal Markings

All longitudinal lines shall be clearly and sharply delineated, straight and true on tangent, and form a smooth curve where required. Lines shall be square at both ends, without mist, drip or spatter.

A solid line shall be continuous. A broken line shall consist of 10 ft line segments with 30 ft gaps.

All lines shall be gapped at intersections unless otherwise specified or directed.

The actual repainting limits for no-passing zone markings will be determined by the Engineer.

A new broken line placed over an existing broken line shall laterally match the existing broken line, and the new line segments shall not extend longitudinally more than 10% beyond either end of the existing line segments.

(a) Center Lines

Center lines shall be used to separate lanes of traffic moving in opposite directions. All center line markings shall be yellow in color and 4 in. in width. They shall

be placed such that the edge of the marking, nearest to the geometric centerline of the roadway, shall be offset 4 in. from the geometric centerline.

The center line of a multi-lane roadway shall be marked with a double solid line. The 2 lines forming the double solid line shall be spaced 8 in. apart and shall be equally offset on opposite sides of the geometric centerline.

The center line of a 2-lane, 2-way roadway, where passing is allowed in both directions, shall be marked with a broken line.

The center line of a 2-lane, 2-way roadway, where passing is allowed in 1 direction only, shall be marked with a double line, consisting of a broken line and a solid line. The broken line and the solid line shall be spaced 8 in. apart and shall be equally offset on opposite sides of the geometric centerline. The solid line shall be offset toward the lane where passing is prohibited. The broken line shall be offset toward the lane where passing is permitted.

The center line shall be placed within the milled corrugation when center line rumble stripes are specified. Placement of the center line marking in the milled corrugation does not alter the pavement marking performance requirements of section 808.07.

(b) Lane Lines

Lane lines shall be used to separate lanes of traffic moving in the same direction. Normal lane line markings shall be white in color and shall be 5 in. wide on freeways, interstates and toll roads, and 4 in. wide on all other roads. They shall be offset 4 in. to the right of longitudinal pavement joints or divisions between traffic lanes. Normal lane lines shall be marked with white broken lines. White solid lines shall be used to mark lane lines only when specified or directed.

(c) Edge Lines

Edge lines shall be used to outline and separate the edge of pavement from the shoulder. Edge line markings shall be 4 in. in width and shall be placed such that the edge of the marking nearest the edge of the pavement shall be offset 4 in. from the edge of the pavement except as otherwise directed. Right edge lines shall be marked with a white solid line and left edge lines shall be marked with a yellow solid line.

The edge line shall be placed in the milled corrugation when edge line rumble stripes are specified. Placement of the edge line marking in the milled corrugation does not alter the pavement marking performance requirements of section 808.07.

(d) Barrier Lines

Barrier lines shall be used as specified or directed. Barrier line markings shall be solid lines of the size and color specified or as directed.

(e) Markings in Retrofitted Corrugations

In sections where corrugations are being placed in the existing surface all existing pavement markings shall be removed in accordance with 808.10 and any existing

sealants shall be routed or grinded out. Temporary pavement markings placed in accordance with 801.12 shall be offset a sufficient distance from the longitudinal joint so as to not to obstruct the installation of the corrugations or the application of the liquid asphalt sealant.

The Contractor shall make a record of the existing pavement marking locations so that such markings may be replicated later with the appropriate adjustments for edge line rumble stripes. This record shall show longitudinal and transverse dimensions. The record shall be submitted to and approved by the District Traffic Engineer prior to the removal of existing pavement markings. The District Traffic Section shall be notified two weeks prior to applying pavement markings so as to allow the District Traffic Section to verify the pavement marking plan.

APPENDIX C. SR 25 CENTERLINE AND EDGELINE CONSTRUCTION PHOTOS

The photographs in this appendix were obtained during the fall 2013 construction of centerline and edgeline rumble stripes on SR 25 in Shadeland and West Point, Indiana. A short video illustrates some of the installation details as well as corrective action drivers take when they drift onto centerline or edgeline rumble stripes.

Access the video here: http://dx.doi.org/10.5703/1288284315340

Figure C.1 Temporary roadway markings.

Figure C.2 Rumble stripe convoy staging.

Figure C.3 Centerline and edgeline markings ground off (but centerline debris not removed).

Figure C.4 Centerline and edgeline ground off.

Figure C.5 Cab of milling truck, note three monitors on visor.

Figure C.6 Camera mounted under milling truck.

Figure C.7 Cameras mounted under milling truck.

Figure C.8 Markings to indicate stop of centerline (CL) rumble.

Figure C.9 Variable message sign panel 1.

Figure C.10 Variable message sign panel 2.

Figure C.11 Flagging operation, preparing for direction change.

Figure C.12 Flagging operation, start of direction change.

Figure C.13 Flagging operation, traffic stopped.

Figure C.14 Flagging operation.

Figure C.15 Flagging operation.

Figure C.16 Rumble stripe convoy.

Figure C.17 Rumble stripe convoy (milling, dump truck, sweeper).

Figure C.18 Rumble milling truck, milling head close up.

Figure C.19 Freshly milled rumbles.

Figure C.20 Freshly milled rumbles.

Figure C.21 Freshly milled rumbles, drip line visible.

Figure C.22 Freshly milled rumbles, drip line visible.

Figure C.23 Edgeline rumble milling.

Figure C.24 Edgeline milling convoy (milling, dump truck, sweeper).

Figure C.25 Edgeline milling convoy (milling, dump truck, and sweeper).

Figure C.26 Edgeline milling convoy (milling, dump truck, and sweeper).

Figure C.27 Joint sealant applied to centerline joint.

Figure C.28 Fog sealant applied to edgeline (thin application).

Figure C.29 Fog sealant applied to edgeline (thin application).

Figure C.30 Fog sealant applied to edgeline (thin application).

Figure C.31 Fog sealant applied to edgeline (thin application).

Figure C.32 Fog sealant applied to edgeline (thin application).

Figure C.33 Fog seal applied to centerline and edgeline.

Figure C.34 Centerline fog seal.

Figure C.35 Centerline fog seal close up.

Figure C.36 Centerline fog seal close up.

Figure C.37 Completed fog seal, completed centerline striping, edgeline guide marks.

Figure C.38 Completed fog seal, completed centerline striping, edgeline guide marks.

Figure C.39 Completed centerline and edgeline markings in Shadeland, Indiana (SR 25).

Figure C.40 Close up of centerline rumble stripe.

Figure C.41 Completed centerline and edgeline markings.

Figure C.42 Completed centerline and edgeline markings in West Point, Indiana (SR 25).

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,500 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: http://docs.lib.purdue.edu/jtrp

Further information about JTRP and its current research program is available at: http://www.purdue.edu/jtrp

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